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1    **Total, regional and unilateral body composition of professional English first-**  
2    **class cricket fast bowlers**

3

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7

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## 1    **Abstract**

2    There have been few reports of advanced body composition profiles of elite fast  
3    bowlers in the sport of cricket. Therefore, the aim of the current study was to  
4    determine total, regional and unilateral body composition characteristics of elite  
5    English first-class cricket fast bowlers in comparison with matched controls, using  
6    dual-energy X-ray absorptiometry (DXA). Twelve male fast bowlers and 12 age-  
7    matched, non-athletic controls received one total-body DXA scan. Anthropometric  
8    data were obtained as well as left and right regional (arms, legs and trunk) fat mass,  
9    lean mass and bone mineral content. Fast bowlers were significantly taller and  
10   heavier than controls ( $P<0.05$ ). Relative to body mass, fast bowlers possessed  
11   greater lean mass in the trunk ( $80.9\pm3.7$  vs.  $76.7\pm5.9\%$ ;  $P=0.047$ ) and bone mineral  
12   content in the trunk ( $2.9\pm0.3$  vs.  $2.6\pm0.3\%$ ;  $P=0.049$ ) and legs ( $5.4\pm0.5$  vs.  
13    $4.6\pm0.6\%$ ;  $P=0.003$ ). In the arm region, fast bowlers demonstrated significantly  
14   greater unilateral differences in bone mineral content ( $10.6\pm6.6$  vs.  $4.5\pm3.9\%$ ;  
15    $P=0.012$ ). This study provides specific body composition values for elite-level fast  
16   bowlers and highlights the potential for muscle and bone imbalances that may be  
17   useful for conditioning professionals. Our findings also suggest beneficial  
18   adaptations in body composition and bone mass in fast bowlers compared with their  
19   non-athletic counterparts.

20

21   **Keywords:** dual-energy x-ray absorptiometry; elite sport; lean mass; body fat; bone  
22   mineral content

23

## 1    **Introduction**

2    Body composition analysis is a common practice in professional sport, allowing  
3    changes in anthropometric and physiological status to be monitored. A number of  
4    techniques are used to achieve this, such as skinfold kinanthropometry, underwater  
5    hydrostatic weighing, bioelectrical impedance analysis and dual-energy X-ray  
6    absorptiometry (DXA; Duthie, Pyne, Hopkins, Livingstone, and Hooper, 2006;  
7    Walsh, Cartwright, Corish, Sugrue, and Wood-Martin, 2011; Ackland et al., 2012).  
8    Depending on the choice of technique, individual levels of fat mass, lean mass,  
9    percentage body fat, fluid status and bone mineral content can be quantified,  
10    providing useful information for coaching staff, sports nutritionists and conditioning  
11    professionals. The three-compartment model (fat mass, lean mass and bone mineral  
12    content) of body composition assessment, such as DXA, is widely recognised as a  
13    criterion technique for measuring both total (Van der Ploeg, Withers, and Laforgia,  
14    2003; Harley, Hind, O'Hara, and Gross, 2009) and regional (Hind, Oldroyd, and  
15    Truscott, 2011) body composition. DXA has recently been used to quantify body  
16    composition characteristics in elite South African cricket players (Micklesfield,  
17    Gray, and Taliep, 2012). However to date, no study has specifically reported the  
18    body composition profiles of English first-class cricket fast bowlers using this  
19    technique.

20            The discipline of fast bowling in cricket is a crucial element of the sport, and  
21    teams at all levels strive to develop bowlers with the ability to generate high ball  
22    release speeds (Wormgoor, Harden, and Mckinon, 2010). Greater ball release speed  
23    reduces the reaction time and impairs the decision-making ability of a batsman  
24    (Worthington, King, and Ranson, 2013) and this may lead to a dismissal or reduction  
25    in the scoring rate (Wormgoor et al., 2010). Hence, a considerable number of studies

1 have sought to identify the technical aspects that define the fastest bowlers (Glazier,  
2 Paradisis, and Cooper, 2000; Portus, Mason, Elliot, Pfiztner, and Done, 2004;  
3 Worthington et al., 2013). In terms of execution, the bowling action is initiated with  
4 a run-up to the wicket that gradually increases in speed before culminating in a final  
5 delivery stride (Ferdinands, Marshall, and Kersting, 2010). During this sequence a  
6 bowler is required to extend and rotate the trunk whilst absorbing ground reaction  
7 forces of between 3.8–9.0 times body mass at front foot contact (Hurion, Dyson,  
8 and Hale, 2000; Stuelcken, Ferdinands, and Sinclair, 2010).

9 Non-DXA anthropometric profiling has shown that greater anterior-posterior  
10 chest depth and large arm and calf girths are associated with higher ball release  
11 speeds (Pyne, Duthie, Saunders, Petersen, and Portus, 2006; Stuelcken, Pyne, and  
12 Sinclair, 2007; Johnstone et al., 2014). Using DXA, Micklesfield and colleagues  
13 (2012) reported no differences in total fat mass and lean mass in elite South African  
14 fast bowlers compared to batsmen and spin bowlers. The purpose of the current  
15 study was to explore regional and unilateral as well as total three-compartment body  
16 composition in elite English first-class cricket fast bowlers, and to compare these  
17 values with age-matched, non-athletic controls.

18

## 19 **Methods**

### 20 *Participants*

21 Twelve professional male cricket fast bowlers from an English first-class county  
22 club and twelve non-athletic, age-matched controls (age  $22.6 \pm 4.6$  vs.  $21.4 \pm 1.6$   
23 years, respectively;  $P = 0.437$ ) participated in the study. For the purpose of this

1 study, the term 'fast bowler' refers to a player who would normally bowl seam up and  
2 in normal circumstances, the keeper would stand back to take the ball, given the  
3 greater ball velocity compared to slower bowlers (Dennis, Farhart, Goumas, and  
4 Orchard, 2003). Controls were recruited from non-athletic university staff and  
5 students not engaged in a structured programme of exercise. The age range of both  
6 groups was 17.0–30.1 years for fast bowlers, and 18.0–23.8 years for controls. By  
7 ethnicity, there were 11 Caucasians and 1 Asian participant in each sample group.  
8 Prior to testing all participants provided their written, informed consent to take part.  
9 Approval for the study was granted by the University Faculty Research Ethics  
10 Committee in accordance with the guidelines of the Declaration of Helsinki.

11

## 12 *Experimental design*

13 Participants underwent a single total-body DXA scan (Lunar iDXA, GE Healthcare,  
14 Madison, WI) during the preseason phase of the cricket season (January) in a  
15 euhydrated state. Participants were instructed to wear light weight clothing and  
16 remove all shoes and jewellery prior to testing. Height was measured using a  
17 stadiometer (SECA Alpha, Birmingham, UK) to the nearest millimetre and body  
18 mass was measured using calibrated electronic scales (SECA Alpha 770,  
19 Birmingham, UK) to the nearest gram. Participants were asked to lie on the scanning  
20 table in a supine position, with arms to the side and ankles supported with the Lunar  
21 ankle strap. Each scan took approximately 7 minutes to obtain values for total fat  
22 mass, lean mass, percentage body fat and bone mineral content. Bone mineral  
23 content is the amount of bone mineral (hydroxyapatite) within a given anatomical  
24 region, and provides one indication of bone strength. Lean mass and fat mass data

1 were calculated based upon the ratio of soft tissue attenuation of two X-ray energy  
2 beams for each pixel containing a minimum amount of soft tissue but no significant  
3 bone (Mazess, Barden, Bisek, and Hanson, 1990). Bone mineral content was then  
4 determined from the absorption of each beam by bone.

5 In our laboratory, the *in-vivo* short-term precision (%CV) for total body  
6 composition variables are 0.82% for fat mass, 0.51% for lean mass, 0.86% for  
7 percentage body fat, and 0.60% for bone mineral content (Hind et al., 2011). All  
8 scanning and analysis procedures were completed by the same trained operator using  
9 the GE Lunar ENCORE software package (Version 15.0) and interpreted by an  
10 International Society for Clinical Densitometry (ISCD) clinically certified  
11 densitometrist. The machine was checked and calibrated on a daily basis in  
12 accordance with the manufacturer's recommendations.

13

#### 14 *Statistical analyses*

15 All statistical analysis procedures were completed using the SPSS software package  
16 (Version 21.0, SPSS Inc., Chicago, IL). Normality and equality of variance in the  
17 data were assessed using the Shapiro-Wilk test, normality plots and Levene's test  
18 where appropriate. Descriptive statistics were used to profile each of the sample  
19 groups, with data reported as mean  $\pm$  standard deviation. For regional data both  
20 absolute and relative values were calculated. The association between lean mass and  
21 bone mass was determined using the Pearson product-moment correlation.

22 Independent samples t-tests were used to compare body size and composition  
23 variables of fast bowlers and controls. Dependent samples t-tests were used to  
24 compare differences in body composition between the legs (front leg vs. back leg)



1 and arms (non-bowling vs. bowling). In the event that a variable was found to be  
2 non-parametric, log transformation was performed. Effect size in the form of  
3 Cohen's  $d$  was reported to demonstrate the magnitude of observed differences. A  
4 variation of the effect size scale put forth by Cohen (1988) was used to classify  
5 observed effect size values as follows: 0–0.2 (trivial), 0.2–0.6 (small), 0.6–1.2  
6 (moderate), 1.2–2.0 (large) and >2.0 (very large) (Hopkins, 2002). For effect sizes,  
7 95% confidence intervals (95%CI) were also determined. Statistical significance for  
8 all analyses was set to  $P \leq 0.05$ .

9

## 10 **Results**

11 The descriptive characteristics of the fast bowlers and controls are reported in Table  
12 I. Fast bowlers were significantly taller ( $P = 0.001$ ), heavier ( $P = 0.001$ ) and  
13 possessed greater amounts of lean mass and bone mineral content ( $P < 0.001$ )  
14 compared to controls, with effects ranging from large to very large. Absolute and  
15 relative total fat mass did not significantly differ between groups, nor did body mass  
16 index. The moderately lower percentage body fat in fast bowlers was noted, despite  
17 not reaching statistical significance. Effects for body mass index and fat mass ranged  
18 from trivial to small. The correlation between total lean mass and bone mineral  
19 content was not significant in fast bowlers ( $r = 0.57$ ,  $P = 0.053$ ) but was significant  
20 in controls ( $r = 0.79$ ,  $P = 0.002$ ).

21

22 \*\*\*\*insert Table 1 near here\*\*\*\*

23

1           Regional differences in body composition are shown in Table II. Fast  
2 bowlers possessed significantly higher absolute lean mass and bone mineral content  
3 in the arms, legs and trunk. This was further indicated by the large to very large  
4 effect sizes observed. Absolute fat mass did not differ significantly between groups  
5 in any region. When expressed as % of regional mass, no significant differences  
6 were observed in the arms ( $P > 0.05$ ). Although arm bone mineral content was  
7 moderately greater in fast bowlers, this effect did not reach statistical significance ( $P$   
8 = 0.053). Bone mineral content was significantly higher in the legs of fast bowlers;  
9 this was concurrent with greater lean mass and bone mineral content in the trunk  
10 compared to controls. These differences also constituted moderate to large effects. In  
11 controls, significantly greater relative fat mass was observed in the trunk,  
12 demonstrating a moderate effect. No other significant differences in regional body  
13 composition were observed.

14

15                                   *\*\*\*\*insert Table 2 near here\*\*\*\**

16

17           The percentage differences in unilateral body composition for both groups  
18 are given in Table III. Fast bowlers demonstrated a significantly greater difference in  
19 arm bone mineral content than controls ( $P = 0.012$ ) and this constituted a moderate  
20 effect. A moderately greater difference in leg fat mass was observed in fast bowlers  
21 however this was not statistically significant. No other significant differences were  
22 found and this is further supported by the small/trivial effect size values observed.

1           In fast bowlers, when the front leg was compared to the back leg, no  
2   significant differences were found for fat mass ( $2.59 \pm 0.47$  vs.  $2.63 \pm 0.47$  kg;  $P =$   
3    $0.368$ ;  $d = 0.09 \pm 0.21$ ), lean mass ( $11.53 \pm 1.09$  vs.  $11.62 \pm 1.30$  kg;  $P = 0.473$ ;  $d =$   
4    $0.08 \pm 0.24$ ) or bone mineral content ( $800 \pm 86$  vs.  $792 \pm 97$  g;  $P = 0.177$ ;  $d = 0.09 \pm$   
5    $0.14$ ). For the bowling arm, significantly greater lean mass ( $4.34 \pm 0.43$  vs.  $4.15 \pm$   
6    $0.49$  kg;  $P = 0.021$ ;  $d = 0.22 \pm 0.18$ ) and bone mineral content ( $288 \pm 37$  vs.  $257 \pm 34$   
7   g;  $P < 0.001$ ;  $d = 0.87 \pm 0.38$ ), were observed compared to the non-bowling arm. No  
8   significant differences in fat mass were found ( $0.79 \pm 0.17$  vs.  $0.76 \pm 0.14$  kg;  $P =$   
9    $0.166$ ;  $d = 0.19 \pm 0.28$ ).

10

11                                   *\*\*\*\*insert Table 3 near here\*\*\*\**

12

## 13   **Discussion**

14   To our knowledge this is the first study to present DXA-derived total and regional  
15   body composition values for elite English cricket fast bowlers. It is also the first  
16   investigation to report unilateral differences in body composition in fast bowlers and  
17   an age-matched control group.

18           Fast bowlers were significantly taller than controls, supporting reports  
19   elsewhere that elite fast bowlers are taller than players from other cricketing  
20   disciplines (Micklesfield et al., 2012; Johnstone et al., 2014) as well as the general  
21   male population (Health and Social Care Information Centre, 2012). Typical values  
22   in this population have ranged from 183 cm to 192 cm (Stuelcken et al., 2007;  
23   Wormgoor et al., 2010; Worthington et al., 2013). Increased standing height may be

1 a beneficial attribute for performance in fast bowling, given that a higher angle of  
2 ball release may extract greater bounce from the playing surface (Stuelcken et al.,  
3 2007).

4 The significantly higher body mass, absolute total and regional lean mass  
5 found in fast bowlers indicates a more highly-developed physique (Stuelcken et al.,  
6 2007). The only previous study to compare body mass between fast bowlers and  
7 controls did so in 9 fast bowlers, and found no significant differences in body mass  
8 (Micklesfield et al., 2012). However, previous research in cricket (Pyne et al., 2006)  
9 and other throwing sports (Van den Tillaar and Ettema, 2004; Werner, Suri, Guido,  
10 Meister and Jones, 2008) has shown that increased body mass and lean mass are  
11 linked to both bowling velocity and throwing performance. For example, Pyne and  
12 colleagues (2006) found that anterior-posterior chest depth, measured by  
13 anthropometry, was one factor in a multiple linear regression analysis that showed a  
14 sizeable relationship ( $r = 0.74$ ) with peak bowling speed in 24 senior first-class fast  
15 bowlers. Using a 4-site skinfold analysis model, Van den Tillaar and Ettema (2004)  
16 investigated the effects of anthropometry and gender on maximal overarm throwing  
17 velocity in 20 experienced male handball players. Throwing velocity was found to  
18 correlate with both fat-free mass ( $r = 0.62$ ) and body mass ( $r = 0.54$ ). These findings  
19 are further supported by those of Werner et al. (2008) who conducted a study of ball  
20 velocity and throwing mechanics in 54 collegiate baseball players using three-  
21 dimensional, high-speed (240 Hz) video analysis. It was found that heavier pitchers  
22 tended to throw faster than lighter pitchers, perhaps due to the possession of greater  
23 lean mass and strength (Werner et al., 2008).

24 In our study, the observation that no significant differences in fat mass were  
25 found between fast bowlers and controls suggests that the difference in body mass

1 between groups was predominantly lean mass, and this may be desirable for  
2 performance (Van den Tillaar and Ettema, 2004; Pyne et al., 2006). Further, the  
3 greater absolute and relative lean mass and decreased relative fat mass of the trunk  
4 region (Table II) in fast bowlers is indicative of an optimised body composition, in  
5 which the ratio of lean mass to fat mass is maximised, thus enhancing performance  
6 (Van den Tillaar and Ettema, 2004; Pyne et al., 2006; Stuelcken et al., 2007). The  
7 fact that the measurements were taken during preseason, at a time of considerable  
8 emphasis on training and physical development (Milanese, Piscitelli, Lampis, and  
9 Zancanaro, 2012) may have also contributed to this profile. As outlined previously,  
10 increased levels of lean mass may be beneficial for fast bowlers to enhance bowling  
11 velocity and accuracy (Pyne et al., 2006; Stuelcken et al., 2007; Johnstone et al.,  
12 2014). Furthermore, the development of lean mass may be beneficial for fast bowlers  
13 with regards to injury prevention (Stuelcken et al., 2007).

14         The greater total and relative bone mineral content of the legs and trunk in  
15 fast bowlers may be indicative of the loading placed upon them, with particular  
16 emphasis on the lower limbs and lumbar spine (Finch, Elliot, and McGrath, 1999;  
17 Hurron et al., 2000). It has been speculated that high levels of bone mass in fast  
18 bowlers may be a consequence of their high lean mass (Micklesfield et al., 2012).  
19 The 'muscle-bone unit' theory suggests that both muscle and bone, as highly  
20 metabolic endocrine organs, are capable of bidirectional crosstalk via myokines and  
21 osteokines (Cianferotti and Brandi, 2014). Thus, striated muscle can influence bone  
22 strength (Cianferotti and Brandi, 2014). Although in our study, the correlation  
23 between bone mineral content and lean mass was large, this did not reach statistical  
24 significance. It is more likely that the ground reaction forces endured by fast bowlers  
25 in the run-up and delivery stride contribute an osteogenic effect, in line with Frost's

1 Mechanostat theory (Frost, 1987). The Mechanostat is a negative feedback system  
2 responsible for bone modelling and remodelling, influenced by mechanical,  
3 hormonal and cell signalling mechanisms (Schoenau and Fricke, 2006). Indeed, the  
4 high-impact nature of fast bowling may itself be responsible for beneficial  
5 adaptations in bone mass and appendicular lean mass in this population (Andreoli et  
6 al., 2001; Micklesfield et al., 2012). However, it should also be noted that excessive  
7 repetitive loading of significant magnitude, such as that induced by a high bowling  
8 workload, may result in skeletal micro-trauma leading to overuse injuries such as  
9 lumbar stress fractures (Dennis, Finch, and Farhart, 2005).

10         The significantly greater unilateral difference in arm bone mineral content in  
11 fast bowlers may be a consequence of muscular and osseous adaptations in the  
12 bowling (dominant) arm. This has been demonstrated in other sports such as tennis  
13 and baseball as well as in collegiate throwing athletes (McClanahan et al., 2002;  
14 Whittington et al., 2009). These adaptations are likely a result of the increased  
15 muscular forces applied during bowling and throwing when compared to the non-  
16 dominant arm. For example, Glazier and colleagues (2000) found that the arm action  
17 contributed 62.2% of ball release speed, using three-dimensional biomechanical  
18 analysis. Large distraction forces are experienced at the glenohumeral joint during  
19 the early stages of the follow-through of the bowling action, requiring the  
20 appropriate dynamic stability to maintain structural integrity at the joint (Stuelcken,  
21 Ferdinands, Ginn, and Sinclair, 2010). Concurrent with the Mechanostat and muscle-  
22 bone unit theories, dynamic muscular forces generated within the bowling arm of  
23 fast bowlers may be sufficient to instigate a site-specific osteogenic response  
24 (Schoenau and Fricke, 2006). Importantly, the presence of muscle and/or bone  
25 imbalances in overhead throwing athletes may be associated with an increased risk

1 of injury due to functional instability and movement impairments (Wang and  
2 Cochrane, 2001; Page, 2011; Edouard et al., 2013; Mangine et al., 2014). In this  
3 study, no significant unilateral differences in body composition were found in the  
4 trunk region. By DXA, the trunk includes the complete spine and can be confounded  
5 by the sternum and rib cage. The skeletal response to long-term fast bowling in the  
6 lumbar spine would enable a more appropriate exploration of the effects of  
7 repetitive, dynamic forces at a site of frequent injury in this population (Finch et al.,  
8 1999).

9

## 10 **Conclusions**

11 To our knowledge this is the first investigation to quantify total, regional and  
12 unilateral body composition in fast bowlers using a three-compartment model. Our  
13 findings suggest that fast bowlers possess greater total lean mass and bone mineral  
14 content than non-athletic controls. Furthermore, fast bowlers demonstrated higher  
15 relative lean mass and bone mineral content in the trunk and legs. These data may  
16 provide guide values for strength and conditioning professionals and coaching  
17 personnel, particularly with consideration to development athletes in the sport of  
18 cricket. Crucially, the existence of unilateral differences in these variables by way of  
19 muscular and osseous imbalances may pose practical implications for the design of  
20 training programmes to potentially improve performance and/or reduce injury risk.  
21 Future research to prospectively investigate the relationships of bone and body  
22 composition with injury occurrence in a larger sample of fast bowlers over the  
23 course of a complete first-class season is warranted.

24

1   **References**

2

3   Ackland, T.R., Lohman, T.G., Sundgot-Borgen, J., Maughan, R.J., Meyer, N.L.,  
4   Stewart, A.D., and Müller, W. (2012). Current status of body composition  
5   assessment in sport: review and position statement on behalf of the ad hoc research  
6   working group on body composition health and performance, under the auspices of  
7   the I.O.C. Medical Commission. *Sports Medicine*, 42, 227-249.

8

9   Andreoli, A., Monteleone, M., Van Loan, M., Promenzio, L., Tarantino, U., and De  
10   Lorenzo, A. (2001). Effects of different sports on bone density and muscle mass in  
11   highly trained athletes. *Medicine and Science in Sports and Exercise*, 33, 507-511.

12

13   Cianferotti, L., and Brandi, M.L. (2014). Muscle-bone interactions: basic and clinical  
14   aspects. *Endocrine*, 45, 165-177.

15

16   Cohen, J. (1988). *Statistical Power Analysis for the Behavioural Sciences*, (2nd ed.).  
17   Hillsdale, NJ: Lawrence Erlbaum.

18

19   Dennis, R., Farhart, R., Goumas, C., and Orchard, J. (2003). Bowling workload and  
20   the risk of injury in elite cricket fast bowlers. *Journal of Science and Medicine in*  
21   *Sport*, 6, 359-367.



1

2 Dennis, R.J., Finch, C.F., and Farhart, P.J. (2005). Is bowling workload a risk factor  
3 for injury to Australian junior cricket fast bowlers? *British Journal of Sports*  
4 *Medicine*, 39, 843-846.

5

6 Duthie, G.M., Pyne, D.B., Hopkins, W.G., Livingstone, S., and Hooper, S.L. (2006).  
7 Anthropometry profiles of elite rugby players: quantifying changes in lean mass.  
8 *British Journal of Sports Medicine*, 40, 202-207.

9

10 Edouard, P., Degache, F., Oullion, R., Plessis, J.Y., Gleizes-Cervera, S., and  
11 Calmels, P. (2013). Shoulder strength imbalances as injury risk in handball.  
12 *International Journal of Sports Medicine*, 34, 654-660.

13

14 Ferdinands, R., Marshall, R.N., and Kersting, U. (2010). Centre of mass kinematics  
15 of fast bowling in cricket. *Sports Biomechanics*, 9, 139-152.

16

17 Finch, C.F., Elliot, B.C., and McGrath, A.C. (1999). Measures to prevent cricket  
18 injuries: an overview. *Sports Medicine*, 28, 263-272.

19

20 Frost, H.M. (1987). Bone “mass” and the “mechanostat”: a proposal. *The*  
21 *Anatomical Record*, 219, 1-9.

1

2 Glazier, P.S., Paradisis, G.P., and Cooper, S-M. (2000). Anthropometric and  
3 kinematic influences on release speed in men's fast-medium bowling. *Journal of*  
4 *Sports Sciences*, 18, 1013-1021.

5

6 Harley, J.A., Hind, K., O'Hara, J., and Gross, A. (2009). Validation of the skin-fold  
7 thickness method and air displacement plethysmography with dual energy X-ray  
8 absorptiometry, for the estimation of % body fat in professional male rugby football  
9 league players. *International Journal of Body Composition Research*, 7, 7-14.

10

11 Health and Social Care Information Centre. (2012). Health Survey for England.  
12 Available at: [http://www.hscic.gov.uk/catalogue/PUB13218/HSE2012-Ch10-Adult-](http://www.hscic.gov.uk/catalogue/PUB13218/HSE2012-Ch10-Adult-BMI.pdf)  
13 [BMI.pdf](http://www.hscic.gov.uk/catalogue/PUB13218/HSE2012-Ch10-Adult-BMI.pdf). Accessed 3 July 2014.

14

15 Hind, K., Oldroyd, B., and Truscott, J.G. (2011). In vivo precision of the GE Lunar  
16 iDXA densitometer for the measurement of total body composition and fat  
17 distribution in adults. *European Journal of Clinical Nutrition*, 65, 140-142.

18

19 Hopkins, W.G. (2002). A new view of statistics: effect magnitudes. Retrieved from  
20 <http://www.sportsci.org/resource/stats/effectmag.html>.

21

- 1 Hurriion, P.D., Dyson, R., and Hale, T. (2000). Simultaneous measurement of back  
2 and front foot ground reaction forces during the same delivery stride of the fast-  
3 medium bowler. *Journal of Sports Sciences*, 18, 993-997.
- 4
- 5 Johnstone, J.A., Mitchell, A.C., Hughes, G., Watson, T., Ford, P.A., and Garrett,  
6 A.T. (2014). The athletic profile of fast bowling in cricket: a review. *Journal of*  
7 *Strength and Conditioning Research*, 28, 1465-1473.
- 8
- 9 Mangine, G.T., Hoffman, J.R., Gonzalez, A.M., Jajtner, A.R., Scanlon, T.,  
10 Rogowski, J.P., Wells, A.J., Fragala, M.S., and Stout, J.R. (2014). Bilateral  
11 differences in muscle architecture are associated with increased rate of injury in  
12 National Basketball Association players. *Journal of Athletic Training*, 49, 000-000  
13 [Epub ahead of print].
- 14
- 15 Mazess, R.B., Barden, H.S., Bisek, J.P., and Hanson, J. (1990). Dual-energy x-ray  
16 absorptiometry for total-body and regional bone mineral and soft-tissue composition.  
17 *American Journal of Clinical Nutrition*, 51, 1106-1112.
- 18
- 19 McClanahan, B.S., Harmon-Clayton, K., Ward, K.D., Klesges, R.C., Vukadinovich,  
20 C.M., and Cantler, E.D. (2002). Side-to-side comparisons of bone mineral density in  
21 upper and lower limbs of collegiate athletes. *Journal of Strength and Conditioning*  
22 *Research*, 16, 586-590.

1

2 Micklesfield, L.K., Gray, J., and Taliep, M.S. (2012). Bone mineral density and body  
3 composition of South African cricketers. *Journal of Bone and Mineral Metabolism*,  
4 30, 232-237.

5

6 Milanese, C., Piscitelli, F., Lampis, C., and Zancanaro, C. (2012). Effect of a  
7 competitive season on anthropometry and three-compartment body composition in  
8 female handball players. *Biology of Sport*, 29, 199-204.

9

10 Page, P. (2011). Shoulder muscle imbalance and subacromial impingement  
11 syndrome in overhead athletes. *International Journal of Sports Physical Therapy*, 6,  
12 51-58.

13

14 Portus, M.R., Mason, B.R., Elliot, B.C., Pfitzner, M.C., and Done, R.P. (2004).  
15 Technique factors related to ball release speed and trunk injuries in high performance  
16 cricket fast bowlers. *Sports Biomechanics*, 3, 263-283.

17

18 Pyne, D.B., Duthie, G.M., Saunders, P.U., Petersen, C.A., and Portus, M.R. (2006).  
19 Anthropometric and strength correlates of fast bowling speed in junior and senior  
20 cricketers. *Journal of Strength and Conditioning Research*, 20, 620-626.

21

- 1 Schoenau, E., and Fricke, O. (2006). Interaction between muscle and bone. *Hormone*  
2 *Research*, 66, 73-78.
- 3
- 4 Stuelcken, M., Pyne, D., and Sinclair, P. (2007). Anthropometric characteristics of  
5 elite cricket fast bowlers. *Journal of Sports Sciences*, 25, 1587-1597.
- 6
- 7 Stuelcken, M.C., Ferdinands, R.E.D., and Sinclair, P.J. (2010). Three-dimensional  
8 trunk kinematics and low back pain in elite female fast bowlers. *Journal of Applied*  
9 *Biomechanics*, 26, 52-61.
- 10
- 11 Stuelcken, M.C., Ferdinands, R.E.D., Ginn, K.A., and Sinclair, P.J. (2010). The  
12 shoulder distraction force in cricket fast bowling. *Journal of Applied Biomechanics*,  
13 26, 373-377.
- 14
- 15 Van den Tillaar, R., and Ettema, G. (2004). Effect of body size and gender in  
16 overarm throwing performance. *European Journal of Applied Physiology*, 91, 413-  
17 418.
- 18
- 19 Van der Ploeg, G.E., Withers, R.T., and Laforgia, J. (2003). Percent body fat via  
20 DEXA: comparison with a four-compartment model. *Journal of Applied Physiology*,  
21 94, 499-506.

1

2 Walsh, M., Cartwright, L., Corish, C., Sugrue, S., and Wood-Martin, R. (2011). The  
3 body composition, nutritional knowledge, attitudes, behaviours, and future education  
4 needs of senior schoolboy rugby players in Ireland. *International Journal of Sport*  
5 *Nutrition and Exercise Metabolism*, 21, 365-376.

6

7 Wang, H.K., and Cochrane, T. (2001). Mobility impairment, muscle imbalance,  
8 muscle weakness, scapular asymmetry and shoulder injury in elite volleyball  
9 athletes. *The Journal of Sports Medicine and Physical Fitness*, 41, 403-410.

10

11 Werner, S.L., Suri, M., Guido, J.A. Jr., Meister, K., and Jones, D.G. (2008).  
12 Relationships between ball velocity and throwing mechanics in collegiate baseball  
13 pitchers. *Journal of Shoulder and Elbow Surgery*, 17, 905-908.

14

15 Whittington, J., Schoen, E., Labounty, L.L., Hamdy, R., Ramsey, M.W., Stone,  
16 M.E., Sands, W.A., Haff, G.G., and Stone, M.H. (2009). Bone mineral density and  
17 content of collegiate throwers: influence of maximal strength. *The Journal of Sports*  
18 *Medicine and Physical Fitness*, 49, 464-473.

19

20 Wormgoor, S., Harden, L., and Mckinon, W. (2010). Anthropometric,  
21 biomechanical, and isokinetic strength predictors of ball release speed in high-  
22 performance cricket fast bowlers. *Journal of Sports Sciences*, 28, 957-965.

1

2     Worthington, P.J., King, M.A., and Ranson, C.A. (2013). Relationships between fast  
3     bowling technique and ball release speed in cricket. *Journal of Applied*  
4     *Biomechanics*, 29, 78-84.

5

**Table I.** Anthropometric and total-body composition characteristics of fast bowlers and non-athletic, age-matched controls (mean  $\pm$  standard deviation).

	<b>Controls (n=12)</b>	<b>Fast bowlers (n=12)</b>	<b>p value</b>	<b>Effect size <math>\pm</math> 95%CI</b>
Height (cm)	177.3 $\pm$ 7.8	187.7 $\pm$ 5.8	0.001 <sup>a</sup>	1.51 $\pm$ 0.83
Body mass (kg)	74.4 $\pm$ 6.7	84.9 $\pm$ 6.6	0.001 <sup>a</sup>	1.58 $\pm$ 0.86
BMI (kg/m <sup>2</sup> )	23.7 $\pm$ 2.6	24.3 $\pm$ 2.0	0.545	0.26 $\pm$ 0.88
Fat mass (kg)	14.8 $\pm$ 4.7	14.1 $\pm$ 2.6	0.646	0.18 $\pm$ 0.80
Lean mass (kg)	56.5 $\pm$ 3.8	67.0 $\pm$ 5.8	<0.001 <sup>a</sup>	2.14 $\pm$ 0.86
%BF	20.5 $\pm$ 5.0	17.4 $\pm$ 2.9	0.081	0.76 $\pm$ 0.86
BMC (g)	3041 $\pm$ 304	3789 $\pm$ 422	<0.001 <sup>a</sup>	2.03 $\pm$ 0.85

<sup>a</sup> denotes statistical significance at  $P \leq 0.001$ .

%BF percentage body fat; BMC bone mineral content; BMI body mass index



**Table II.** Absolute and relative regional body composition of the arms, legs and trunk in fast bowlers and non-athletic, age-matched controls (mean  $\pm$  standard deviation).

	Controls (n=12)	Fast bowlers (n=12)	p value	Effect size $\pm$ 95%CI
<b>Arms</b>				
FM (kg)	1.6 $\pm$ 0.7	1.6 $\pm$ 0.3	0.728	0.14 $\pm$ 0.82
LM (kg)	7.2 $\pm$ 0.7	8.5 $\pm$ 0.9	0.001 <sup>a</sup>	1.61 $\pm$ 0.88
BMC (g)	428 $\pm$ 42	545 $\pm$ 68	<0.001 <sup>a</sup>	2.07 $\pm$ 0.81
FM (%)	17.2 $\pm$ 5.4	14.9 $\pm$ 2.9	0.201	0.53 $\pm$ 0.83
LM (%)	78.0 $\pm$ 4.9	79.9 $\pm$ 2.9	0.249	0.47 $\pm$ 0.82
BMC (%)	4.7 $\pm$ 0.7	5.2 $\pm$ 0.5	0.053	0.82 $\pm$ 0.83
<b>Legs</b>				
FM (kg)	5.0 $\pm$ 1.6	5.2 $\pm$ 0.9	0.763	0.15 $\pm$ 1.02
LM (kg)	19.6 $\pm$ 1.8	23.1 $\pm$ 2.3	<0.001 <sup>a</sup>	1.69 $\pm$ 0.83
BMC (g)	1181 $\pm$ 141	1592 $\pm$ 183	<0.001 <sup>a</sup>	2.52 $\pm$ 0.84
FM (%)	19.2 $\pm$ 4.5	17.5 $\pm$ 3.0	0.276	0.44 $\pm$ 0.82
LM (%)	76.2 $\pm$ 4.1	77.2 $\pm$ 2.9	0.485	0.28 $\pm$ 0.82
BMC (%)	4.6 $\pm$ 0.6	5.4 $\pm$ 0.5	0.003 <sup>b</sup>	1.45 $\pm$ 0.90
<b>Trunk</b>				
FM (kg)	7.3 $\pm$ 2.5	6.5 $\pm$ 1.6	0.366	0.38 $\pm$ 0.85
LM (kg)	26.4 $\pm$ 2.0	32.2 $\pm$ 3.2	<0.001 <sup>a</sup>	2.17 $\pm$ 0.84
BMC (g)	913 $\pm$ 100	1152 $\pm$ 194	0.001 <sup>a</sup>	1.55 $\pm$ 0.85
FM (%)	20.7 $\pm$ 6.1	16.2 $\pm$ 3.6	0.039 <sup>b</sup>	0.90 $\pm$ 0.85
LM (%)	76.7 $\pm$ 5.9	80.9 $\pm$ 3.7	0.047 <sup>b</sup>	0.85 $\pm$ 0.84
BMC (%)	2.6 $\pm$ 0.3	2.9 $\pm$ 0.3	0.049 <sup>b</sup>	1.00 $\pm$ 1.00

<sup>a</sup> denotes statistical significance at  $P \leq 0.001$ .

<sup>b</sup> denotes statistical significance at  $P \leq 0.05$ .

*BMC* bone mineral content; *FM* fat mass; *LM* lean mass

**Table III.** Percentage (%) differences in unilateral body composition of fast bowlers and non-athletic, age-matched controls (mean  $\pm$  standard deviation).

	Controls (n=12)	Fast bowlers (n=12)	p value	Effect size $\pm$ 95%CI
<b>Arms</b>				
FM	6.20 $\pm$ 6.11	3.51 $\pm$ 2.88	0.182	0.56 $\pm$ 0.84
LM	4.45 $\pm$ 2.90	4.46 $\pm$ 3.44	0.991	0.00 $\pm$ 0.81
BMC	4.51 $\pm$ 3.85	10.59 $\pm$ 6.64	0.012 <sup>a</sup>	1.12 $\pm$ 0.85
<b>Legs</b>				
FM	2.67 $\pm$ 2.23	4.34 $\pm$ 2.92	0.131	0.64 $\pm$ 0.85
LM	3.23 $\pm$ 2.75	3.01 $\pm$ 2.05	0.844	0.08 $\pm$ 0.83
BMC	2.38 $\pm$ 1.74	2.28 $\pm$ 1.66	0.889	0.06 $\pm$ 0.88
<b>Trunk</b>				
FM	5.42 $\pm$ 5.89	5.95 $\pm$ 4.64	0.551	0.10 $\pm$ 0.34
LM	3.60 $\pm$ 3.02	3.54 $\pm$ 3.34	0.859	0.07 $\pm$ 0.81
BMC	4.91 $\pm$ 4.57	4.80 $\pm$ 4.18	0.890	0.06 $\pm$ 0.89

<sup>a</sup> denotes statistical significance at  $P \leq 0.05$ .

*BMC* bone mineral content; *FM* fat mass; *LM* lean mass